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The Effect of Certain Sprays Upon the Apparent Photosynthetic Activity of Apple Trees

by

E. L. Overholser, D. F. Allmendinger,
and F. L. Overley

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The Effect of Certain Sprays Upon the Apparent Photosynthetic Activity of Apple Leaves[1]

E. L. Overholser, D. F. Allmendinger, and F. L. Overley.

Introduction

Certain sprays, used in codling moth and mite control,[2] affect the growth of fruit and color of apples, and may reduce fruit bud formation for the next year's crop (Overley, Overholser and Spuler, 1931; Overley, Overholser and Allmendinger, 1939). Experimental data, however, were lacking to show the amount of foliage injury, especially when non-visible, resulting from these spray programs. Hence, experiments were conducted during the summers of 1935 to 1941 inclusive, to determine quantitatively the effect of certain sprays on the functioning of the foliage of apple trees.

The experiments were conducted to determine the effect of different spray materials and spray schedules upon the apparent photosynthetic activity of apple leaves as measured by carbon dioxide absorption.

Procedure and Spray Programs

Promising commercial sprays used in codling moth control were applied to mature bearing apple trees each year of the experiment. Several different sprays were applied in adjacent plots where equipment required for the determination of apparent photosynthetic activity could be used. Table I, Appendix, gives the spray program used each year, together with the number of sprays and the variety of apple receiving the applications.

Method of Determination of Carbon Dioxide Intake by Leaves. The carbon dioxide intake of the leaves was determined with a modification of the apparatus described by Heinicke and Hoffman (1933). Air was drawn over leaves enclosed in cellophane envelopes. A uniform airflow was maintained through the towers by means of a system of Hoke needle valves and water manometers. The air was bubbled through a solution of potassium hydroxide, which absorbed the carbon dioxide. The excess potassium hydroxide was titrated with standard hydrochloric acid.

For the seasons of 1935 to 1937 inclusive, one leaf was enclosed in each envelope with two to four replications for each plot. In 1938,

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[1] Photosynthetic data were collected by J. Keizer, and D. F. Allmendinger for 1935, 1936; J. B. Rogers for 1937 and 1938; and D. F. Allmendinger for 1939, 1940, 1941.

[2] Several of the spray programs studied involved new combinations of materials that were being investigated by the Division of Entomology for the control of codling moth, such as those involving calcium arsenate, nicotine sulphate, and the Dynamite sprays.

the apparatus was changed so as to make possible the enclosing of nine leaves on a terminal in each envelope, with three replications for each plot. Approximately one-ninth of the air that passed over the leaves was drawn through the towers; the remaining eight-ninths was by-passed. The total airflow, controlled with a second set of Hoke needle valves and manometers, was determined, as well as the portion that passed through the absorption towers. This permitted calculation of the ratio of absorption tower airflow to total airflow. In 1940, the apparatus was further changed so as to pass approximately two-ninths of the total airflow, or two liters per minute, through each absorption tower.

For the 1935 and 1936 seasons, individual trees were utilized as a plot, and there were no unsprayed leaves to serve as checks, but the standard spray program for the season was used as a basis for comparison. Beginning with the 1937 season, unsprayed leaves were provided by covering large branches during the spraying operation, but each plot that year consisted of only one tree. Thereafter, several sets of leaves were used on the one to three trees comprising each plot. Only leaves on the south side of the trees in the sun were used, with the exception of the determinations made in 1935. The determinations were made during mid-day.

The photosynthetic determinations were made only on days when the light intensity varied from approximately 5000 to 10,000 foot candles.

The averages of relative humidity, temperature, and carbon dioxide content of the air were determined during the interval of each series of apparent photosynthetic determination. The carbon dioxide content of the air was determined by the check towers of the apparatus. The environmental conditions appeared to be of such uniformity that they were not related to variations in the carbon dioxide intake of the leaves. The temperature during the determinations usually ranged from 75° to 85° F. and averaged approximately 80° F. The relative humidity varied from 40 to 50 per cent. The mgs. of carbon dioxide per liter of air usually varied from approximately .51 to .54.

The determinations made of the apparent photosynthetic activity of apple leaves as influenced by the spray program giving the spray program number, the number of daily determinations, the number of replications for each determination, the total number of leaves utilized per plot during the season, the number of leaves employed per cellophane envelope, and the variety used are summarized in Table II (Appendix).

The data in Table II (Appendix) show that during seven growing seasons, the possible effect of 24 spray programs upon the apparent photosynthetic activity of apple leaves of Jonathan, Winesap and

Delicious varieties was determined. From five to 46 daily photosynthetic determinations were made each year, utilizing a total of three to 81 leaves for each spray program.

PRESENTATION OF EXPERIMENTAL DATA

The data are presented in two sections: (1) the effect of sprays on carbon dioxide intake by leaves; and (2) the relationship of insecticide and spray combinations upon the carbon dioxide intake.

Effects of Sprays on Carbon Dioxide Intake of Leaves

Tables III to IX inclusive, (Appendix) present the average carbon dioxide assimilation by apple foliage for each determination in each plot during the experimental period, the date of each determination, and the date of application of the sprays.

In Table 1 are summarized the data presented in Tables III to IX (Appendix) and comparisons are made among plots with the grand averages for all plots given. A statistical analysis using Student's method was made of the daily averages of carbon dioxide intake and the odds calculated. When the odds are given with the larger figure first (i.e., 22-1), the first named spray of the comparison has less effect on the carbon dioxide intake than the second, and where the larger figure is second (i.e., 1-9999), the reverse is true.

This discussion is primarily based upon the statistical analyses of the data as shown in Table 1, which are in more complete form in Tables III to IX, inclusive (Appendix) and reference is made to the source of the more detailed data in the discussion.

Season of 1935. In 1935, experiments (Table III) indicate that leaves of Jonathan apple trees receiving the lead arsenate-herring oil, spray program 2, calcium arsenate and medium viscosity mineral oil, spray program 3, and calcium arsenate, zinc sulphate, and hydrated lime, spray program 4, absorbed significantly more carbon dioxide than did the leaves of trees receiving the lead arsenate-medium-mineral oil, spray program 1. There were, however, no significant differences among the first three named plots, each of which received eight spray applications.

Jonathan apple leaves sprayed with calcium arsenate and mineral oil showed greater carbon dioxide intake than did leaves sprayed with lead arsenate and mineral oil, or with lead arsenate and herring oil or with calcium arsenate and zinc sulphate. The differences were significant, however, only when calcium arsenate and mineral oil were compared with lead arsenate and mineral oil.

These findings support previous work (Overholser and Overley, 1934) indicating that codling moth sprays of calcium arsenate with zinc sulphate and calcium hydrate as "safeners" did not adversely

Table 1. Comparisons of Carbon Dioxide Assimilation by Apple Leaves of Spray Plots with No Spray or Standard Sprays Used as a Basis for Comparison.

Year	No. runs	Check spray program	Av. CO_2 mgs/dm2/hr	Compared with spray program**	Av. CO_2 mgs/dm2/hr	With odds	Conclusions‡
		§		§			
1935	46	(2) Pb.–H.O.	8.90*	(1) Pb.–M.O.**	6.39	9999-1	Highly significant
				(3) Ca.–M.O.	9.53	1-15	Not significant
				(4) Ca.–Zn.	8.58	6-1	Not significant
1936	11	(5) Pb.–H.O.	13.62	(6) Nic.–M.O.	9.43	3332-1	Significant
				(7) *Pb. Dyn.	13.42	1-1	Not significant
				(8) Ca.–Zn.	16.67	1-9999	Highly significant
		(7) Pb. Dyn. (1st half)	13.42	(6) Nic.–M.O.	9.43	332-1	Significant
				(8) Ca.–Zn.	16.67	1-555	Significant
1936	17	(7) Pb. Dyn. (2nd half)	11.37	(8) Ca.–Zn.	15.51	1-9999	Highly significant
				(9) Ca.–M.O.	13.96	1-4999	Highly significant
		(8) Ca.–Zn.	15.51	(9) Ca.–oil	13.96		Highly significant
1937	30	(10) Pb. Dyn.	7.78	(11) Ca.–Dyn.	8.73	1-110	Significant
				(12) Pb.–Mod. Dyn.	9.70	1-9999	Highly significant
	30	Unsprayed	12.77	(11) Ca.–Dyn.	8.73	9999-1	Highly significant
			11.04	(12) Pb.-Mod. Dyn.	9.70	57-1	Significant
			12.88	(10) Pb.-Dyn.	7.78	9999-1	Highly significant
1938	20	Unsprayed	9.55	(13) Pb.–Mod. Dyn.	10.01	1-7	Not significant
				(14) Pb. Dyn.+Fl.+H.O.	10.06	1-3	Not significant
				(15) Nic.+Fl.+H.O.	9.90	1-3	Not significant
				(16) Ca.–oil+Fl.+H.O.	9.38	1-1	Not significant

1939	5†	Unsprayed	8.28	(17) Nic.–bent.	8.76	1-3	Not significant
			10.89	(18) Pb.–Mod. Dyn.+Fl.	11.06	1-1	Not significant
			9.34	(19) Pb.–Dyn.+Fl.	7.55	22-1	Slightly significant
1940	14	Unsprayed	12.48	(20) Pb.+Fl.+H.O.	11.89	4-1	Not significant
			11.97	(21) Pb.–oil	12.41	4-1	Not significant
			14.05	(22) Xanthone	12.66	39-1	Significant
1941	14	Unsprayed	11.9	(23) Pb.–oil	10.9	28-1	Slightly significant
	9			(24) Fluorine–oil	10.1	322-1	Significant

§ Numbers in parentheses refer to the spray program used for the year involved and are found in Table I, (Appendix).
* Only 4 cover sprays compared with 5 cover sprays for other plots.
† Fire destroyed laboratory and all apparatus and only 5 runs were possible during the 1939 season.
‡ The conclusions here shown are arrived at by Student's method.

**Pb.—Lead arsenate
Ca.—calcium arsenate
Nic.—nicotine sulphate
Zn.—zinc sulphate
M.O.—mineral oil

H.O.—Herring oil
Dyn.—Dynamite
Mod. Dyn.—modified Dynamite
Fl.—cryolite
+Fl.—cryolite in second brood

affect Jonathan apple leaves as measured by carbon dioxide intake. This previous work also indicated that the use of calcium arsenate and mineral oil is less likely to adversely affect apple foliage than is the use of lead arsenate and mineral oil.

Field records and observations support the photosynthetic studies, in that the trees receiving spray programs 2, 3, and 4 produced the largest harvested crop with the least preharvest fruit drop. The boxes of apples harvested per tree from the plots were as follows: (a) Spray program 2 averaged 14.4; (b) spray program 3 averaged 13.0; and (c) spray program 4 averaged 15.2 boxes. The trees receiving spray program 1 were the least productive, producing only an average of seven boxes per tree. The color of apples from trees receiving spray program 1 was the poorest of any of the 1935 season plots, notwithstanding the fact that only about one-half the quantity of fruit was produced per tree.

In 1935 the dormant spray was lime sulphur (32° Beaume) applied one gallon to 11 gallons of water. The use of mineral oil in the summer sprays (spray program 1), the first of which were applied within 70 days after the dormant lime sulphur spray, resulted in a heavy June drop of young fruits (Overholser, Overley, and Allmendinger, 1942).

Season of 1936. With a herring-oil spray program 5, in 1936, similar to spray program 2 in 1935, (Table IV), the Jonathan leaves absorbed more carbon dioxide than did leaves receiving the nicotine sulphate and light-medium mineral oil spray program 6 but significantly less than did leaves receiving the calcium arsenate, zinc sulfate, and hydrated lime, spray program 8. The carbon dioxide intake of the leaves receiving spray program 5 was comparable to that of leaves receiving the lead arsenate Dynamite spray, program 7, which, however, received one less spray. The carbon dioxide intake of leaves of trees receiving the lead arsenate Dynamite spray (91 U. R., 65-70 viscosity oil, spray program, for the 1936 season, was significantly better than nicotine-mineral oil, spray program 6. These trees receiving spray program 7, however, received only five sprays while the trees receiving the other spray programs received six sprays during the 1936 season. Furthermore, photosynthesis was significantly poorer for the entire season, as measured by the carbon dioxide intake of the sprayed leaves, than the calcium arsenate-zinc sulfate, spray program 8, and for the second half of the season than the calcium arsenate-oil, spray program 9.

Field observations and records showed that the trees in plot 6, which received five sprays of nicotine sulphate and light-medium mineral oil, suffered early injury to the foliage, and a relatively great fruit drop. The apples were relatively small in size, and were poor in red color development.

These findings substantiate previous observation and experience that oil used with nicotine sulphate without other materials such as lead arsenate, or calcium arsenate, or inert materials such as bentonite, tends to result in more injury than when oil is used in combination with these other materials (Overholser and Overley, 1934).

Season of 1937. A lead arsenate-Dynamite, medium oil spray, program 10, used in 1937 (Table V) resulted in a significantly lower carbon dioxide intake by the leaves than did the lead arsenate-modified Dynamite spray, program 12, containing kerosene. The odds were highly significant that the leaves from unsprayed check trees had a greater carbon dioxide intake than did the leaves receiving the lead arsenate-Dynamite spray, program 10, and calcium arsenate, Dynamite spray, program 11. The carbon dioxide intake of the leaves from check trees was also significantly greater than was the case with leaves sprayed with the lead arsenate-modified Dynamite spray, program 12.

Season of 1938. In 1938, (Table VI), the leaves of the check trees did not absorb significantly more carbon dioxide than the leaves of the sprayed trees; i.e., lead arsenate-modified Dynamite spray, program 13; lead arsenate, Dynamite and fluorine spray, program 14; lead arsenate and herring oil, nicotine sulfate and light mineral oil followed by fluorine and herring oil spray, program 15; and calcium-arsenate and oil followed by fluorine, spray program 16. The trees receiving spray program 13 in 1938 received only five applications of the modified lead arsenate "Dynamite," in contrast with six applications with spray program 12 in 1937. In 1937, the absorption of carbon dioxide by the leaves receiving the spray program 12 was only slightly significantly lower than the intake by unsprayed leaves. With the trees receiving spray programs 14, 15, and 16, a split schedule was used and the last three sprays were of cryolite and herring oil. This split schedule may have accounted for the failure of any of these spray programs to significantly lower the carbon dioxide intake of the sprayed leaves, in comparison with unsprayed leaves.

The studies conducted during 1937 and 1938 with the so-called Dynamite and modified Dynamite sprays (Marshall, 1937) show that the Dynamite[1] sprays depressed the apparent photosynthetic activity

[1] A so-called Dynamite or inverted spray mixture has been defined (Marshall, 1937) as one in which a suspended solid initially wetted by water becomes wetted by mineral oil prior to, or at the moment of impact upon, a sprayed surface. Inversion of arsenical spray mixtures requires the addition of some substance promoting oil-wetting of the arsenical, which is nominally preferentially wetted by water. This substance may be a fatty acid such as oleic acid, a univalent, divalent, or trivalent soap, or other fatty acid compound such as diglycol oleate. The term modified, inverted, or modified Dynamite spray mixtures are used when herring oil and kerosene are employed instead of mineral oil. The Dynamite sprays as originally developed are no longer being recommended or used commercially in the State of Washington, although it is reported that the principle concerned in the Dynamite sprays is utilized in the manufacture of several of the oil spreader-stickers now in use.

of apple leaves much more than did the modified Dynamite sprays. The studies of 1937 showed the unsprayed leaves were significantly greater in carbon-dioxide intake than were leaves receiving six sprays of modified Dynamite, but in 1938, with leaves receiving only five applications of modified Dynamite this was not the case.

Season of 1939. Upon the basis of carbon dioxide intake by leaves, there was some indication in 1939 (Table VII) that the check trees functioned better photosynthetically than did the trees sprayed with lead arsenate-Dynamite followed by cryolite spray, program 19, but there was no significant difference between the check trees and the trees receiving nicotine-bentonite spray, program 17, or the modified Dynamite-cryolite spray, program 18. This failure to obtain any significant reduction in the carbon dioxide intake of the sprayed as contrasted with the unsprayed leaves probably resulted from the fact that the apparent photosynthetic determinations were not begun until the first week of September. Since the last cover spray was applied August 16, the possible effects upon the carbon dioxide intake in all likelihood had been largely dissipated by the time the determinations were made.

The field observations and records show that the trees receiving spray program 19 suffered from relatively heavy June drop, resulting in a light crop of apples. Notwithstanding the light crop, the size of the individual apples was small. This may have resulted from the relatively low carbon dioxide intake by the leaves of these trees because of the spray program 19 that they received, i.e., medium oil in the early Dynamite sprays.

Season of 1940. Xanthone spray, program 22, in 1940 (Table VIII) significantly lowered the carbon dioxide intake of the leaves in comparison with leaves of trees in the unsprayed plots. Lead arsenate and mineral oil, cryolite-herring oil split schedule spray, program 20, and lead arsenate-light mineral oil spray, program 21, did not significantly lower the carbon dioxide intake of leaves in comparison with unsprayed leaves. This similarity in the carbon dioxide intake of the unsprayed leaves and of leaves receiving spray program 20 may have been the result of a split schedule involving four different spray combinations with the last four applications being cryolite and herring oil. This response, therefore, is similar to that noted during the 1938 season. With spray program 21, for the last seven applications a light mineral oil of 50 seconds Saybolt viscosity was used. Light mineral oils have not resulted in appreciable foliage injury.

Field observations and records show that the trees receiving spray program 22 of xanthone suffered from foliage injury, especially from the earlier applications, but a subsequent heavy preharvest fruit drop also occurred.

Season of 1941. In 1941 (Table IX) lead arsenate and light-medium mineral oil spray, program 23, and cryolite and light-medium mineral oil spray, program 24, both significantly lowered the carbon dioxide intake of the leaves in comparison with the unsprayed leaves.

Relationship of Insecticide and Spray Combinations Upon CO_2 Intake of Apple Leaves

The effect of the various insecticides and the combinations in which they were used upon the carbon dioxide intake of sprayed apple leaves is shown in Table 2. The figures in parentheses indicate the spray programs that significantly reduced the carbon dioxide intake of the sprayed leaves. The numbers not in parentheses indicate the spray programs that did not reduce the carbon dioxide intake of the sprayed leaves. Since there were no unsprayed check trees in 1935 and 1936, sprays that resulted in a decreased carbon dioxide intake by the sprayed leaves compared with other sprays were considered as having reduced the carbon dioxide intake. Furthermore, since certain sprays did not reduce the carbon dioxide intake as much as some of the other sprays applied in 1935 and 1936, they are listed in Table 2 as not resulting in reduced carbon dioxide intake of the leaves in comparison with the other sprays.

Oil Viscosity. The data in Table 2 generally show that medium (65 to 75 seconds Saybolt viscosity) and light-medium (60 to 65 seconds Saybolt viscosity) mineral oils used throughout the season, whether with lead arsenate spray programs 1 and 23 respectively, and nicotine spray program 6, (medium oil), or light-medium mineral oil used throughout the season with fluorine spray program 24, reduced the carbon dioxide intake of the foliage. When, however, the last brood sprays were changed to fluorine spray programs 20, 16, and 15, no significant reduction was noted; this was true also with modified Dynamite followed by fluorine second brood sprays, program 18. The use of light (50 to 55 seconds Saybolt viscosity) oils used in spray program 21, however, even when used at a concentration of three quarts per 100 gallons with lead arsenate throughout the season, did not significantly lower the carbon dioxide intake of sprayed apple leaves.

This agrees with previous reports (Overholser, Overley, and Allmendinger, 1942) that in general the number of summer oil applications at the maximum quantities recommended (one and one-fourth gallons of oil emulsion per 100 gallons of spray) should not exceed three, unless the insect injury is likely to become more serious than the oil injury. Viscosity, the unsulphonatable residue values, as well as the concentration should also be considered in determining the number of applications that may be given to apple trees without injury. Oils having a high unsulphonatable residue (90 per cent),

Table 2. The Effect of Insecticides and Spray Combinations Upon the CO_2 Intake of Apple Leaves (Numbers in parentheses are spray programs that reduced and numbers not in parentheses are spray programs that did not reduce carbon dioxide intake by apple leaves; see Table 1).

Spray material	Alone or with spreader	With mineral oil	Mineral oil followed by fluorine second brood	Dynamite	Dynamite followed by fluorine second brood	Modified Dynamite	Modified Dynamite followed by fluorine second brood	Herring oil	Bentonite followed by mineral oil
			Numbers designating the spray programs employed						
Lead arsenate		(1) (23) 21	20	(7) (10)	(19) 14‡	(12)† 13	18	(2)§ (5)§	
Calcium arsenate	4§ 8§	3§ (9)§§	16	(11)					
Nicotine		(6)*	15						17
Xanthone	(22)								
Fluorine		(24)							

*Last spray—calcium arsenate.
†Last spray—calcium arsenate spray program 12 on Winesap, 13 on Delicious.
‡This program involved only two sprays of Dynamite.
§Only in comparison with other leaves. No unsprayed leaves.
§§First 5 cover sprays, calcium arsenate-oil; last cover spray calcium arsenate-Dynamite.

(Overley, Overholser, and Allmendinger, 1939), and low viscosities of 50 to 55 seconds Saybolt or lower properly used at concentrations of one-half per cent actual oil or less can generally be applied throughout the season without significant injury. With light oils, 50 to 55 seconds Saybolt viscosity, any effect of lowering the apparent carbon dioxide intake by apple leaves is exerted for a relatively short period of time following each spray application; with heavier oils of 65 to 70 seconds Saybolt viscosity, this depressing effect upon carbon dioxide intake is exerted over a longer period of time.

Dynamite and Modified Dynamite. The Dynamite (either lead arsenate or calcium arsenate) combinations, even when followed by second brood fluorine sprays, reduced the carbon dioxide intake of the sprayed leaves. The one exception was spray program 14, but this employed only two applications of Dynamite sprays, and the last cover spray of Dynamite was applied about 10 days previous to the first photosynthetic determination. The modified Dynamite sprays, (programs 13 and 18), however, were not so serious in their reduction of carbon dioxide intake of the sprayed foliage as were the Dynamite sprays. The leaves of the Winesap variety in 1937 appeared to be more susceptible to arsenical spray injury with the use of the modified Dynamite spray, program 12, than did the Delicious in 1938.

Calcium Arsenate. The calcium arsenate sprays, where direct comparisons with unsprayed leaves were made, reduced the carbon dioxide intake of the foliage when used with mineral oil, spray program 9, or Dynamite throughout the season, but not when used with oil in the first brood followed by fluorine in the second brood spray, program 16.

Leaves sprayed with calcium arsenate alone or with spreader, or in one case with oil spray, programs 4, 8, and 3, did not have a reduced carbon dioxide intake when compared with other sprayed leaves. There were, however, no unsprayed leaves for comparison with these treatments.

Xanthone. The xanthone spray program 22 reduced the carbon dioxide intake of the apple foliage in comparison with unsprayed foliage. Field records showed that trees receiving this spray suffered foliage injury and a heavy preharvest fruit drop.

Herring Oil. The use of herring oil applied throughout the season in combination with lead arsenate spray, programs 2 and 5, seemed to slightly reduce the carbon dioxide intake of apple foliage although the reduction was not as great as with mineral oil and lead arsenate. This agrees with previous reports (Overholser, Overley, and Allmendinger, 1942) that fish oils in the relatively small amounts recommended (one pint per 100 gallons) tend to be less injurious to

fruit and foliage of apples than do mineral oils employed at the larger concentrations commercially used. Nevertheless, when poor quality fish oil has been used, or a poor emulsion results, or too many applications are made, some foliage or fruit injury may result. Fish oil for spraying apple trees should be clear, remain liquid at 65° F., slow-drying, and have an iodine number below 145.

Split Schedules. The data suggest that in so far as minimizing reduction in the carbon dioxide intake of apple foliage, there is a possible benefit in the use of so-called split schedules employing lead arsenate for the first brood sprays and fluorine for the second brood sprays. This appears preferable to the continuous use throughout the season of either lead arsenate or fluorine. When used with mineral oil throughout the season, fluorine did reduce the carbon dioxide intake of the sprayed leaves.

SUMMARY

1. The use of medium-, and light-medium oils throughout the season in the control of codling moth tends to lower the apparent carbon dioxide intake of apple leaves.

2. The use of light-medium oil with fluorine throughout the season reduced the carbon dioxide intake of apple leaves.

3. The use of light mineral oil with first brood codling moth sprays involving lead arsenate and nicotine sulphate, or lead arsenate and calcium arsenate, or lead arsenate or modified Dynamite, followed in each case by fluorine second brood sprays did not reduce carbon dioxide intake of apple leaves.

4. The use of light mineral oil and lead arsenate throughout the season did not significantly lower the carbon dioxide intake of apple leaves.

5. The use of either lead arsenate or calcium arsenate Dynamite combinations even when followed by second brood fluorine sprays reduced the carbon dioxide intake of apple leaves.

6. The use of modified Dynamite sprays were not so serious in their reduction of carbon dioxide intake by apple leaves as were the Dynamite sprays.

7. Herring oil in the relatively small amount recommended (one pint per 100 gallons) tends to be less injurious to foliage, than do medium (65 to 75 viscosity) or light-medium (60-65 viscosity) mineral oils at larger concentrations of one-half to one gallon per 100 gallons, used commercially.

8. The use of calcium arsenate with mineral oil is less likely to reduce carbon dioxide intake of apple leaves, than is the use of lead arsenate with the same amounts of comparable oils.

9. Calcium arsenate with adequate amounts of "safeners" such as zinc sulphate and calcium hydrate may be used without materially affecting the carbon dioxide intake of apple leaves.

10. The use of oils with nicotine sulphate, without other materials, resulted in a greater reduction of carbon dioxide intake by apple leaves than when comparable oils in similar amounts were used with calcium arsenate, lead arsenate, or bentonite.

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Table I. Spray Programs Received by Apple Trees Used in the Photosynthetic Experiments, 1935-1941 Inclusive.

Year	Spray program No.	Materials used per 100 gallons	Apple variety	Number of sprays
1935	1	3 lbs. lead arsenate plus 1 gal. emulsified medium mineral oil (90 U. R. 65-70 viscosity). Dor. spy. L. S. 1 to 11	Jonathan	8
	2	3 lbs. lead arsenate plus 1 pt. herring oil; plus 5 per cent oleic acid. Dor. Spy. L. S. 1 to 11	Jonathan	8
	3	4 lbs. calcium arsenate plus 1 gal. emulsified medium mineral oil (90 U.R. 65-70 viscosity). Dor. Spy. L. S. 1 to 11	Jonathan	8
	4	4 lbs. calcium arsenate plus 2 lbs hydrated lime, plus 1 lb anhydrous zinc sulphate. Dor Spy. L. S. 1 to 11	Jonathan	8
1936	5	3 lbs. lead arsenate plus 1 pt. herring oil, plus 5 per cent oleic acid.	Jonathan	6
	6	One-half pt. nicotine sulphate, 0.61 gal. light medium mineral oil emulsion (91 U.R. 60-65 viscosity)	Jonathan	5
		3 lbs. calcium arsenate, 2 qts. medium mineral oil, (91 U. R. 65-70 visc.) plus 0.17 lb. ammonium oleate, plus 4 oz. zinc sulphate (Ca. arsenate Dynamite)		1
	7	3 lbs. lead arsenate, 2 qts. medium mineral oil (91 U.R. 65-70 visc.) plus 0.17 lb ammonium oleate, plus 4 oz. zinc sulphate (Lead arsenate Dynamite)	Jonathan	5
	8	4 lbs. calcium arsenate, 2 lbs. hydrated lime, 1 lb. zinc sulphate, 2 lbs. Sherwin-Williams dry sulphur	Jonathan	5
		Same, except sulphur omitted		1
	9	4 lbs. calcium arsenate, ½ lb. zinc sulphate, 0.61 gal. medium mineral oil emulsion (91 U. R. 65-70 visc.)	Jonathan	5
		3 lbs. calcium arsenate, 2 qts. medium mineral oil (91 U.R. 65-70 visc.) plus 0.17 lb ammonium oleate, plus 4 ozs. zinc sulphate (Ca. arsenate Dynamite)		1

Table 1, (Continued)

Year	Spray program No.	Materials used per 100 gallons	Apple variety	Number of sprays
1937	10	3 lbs. lead arsenate, 2 qts. medium mineral oil (92 U. R. 65-70 visc.) 0.17 lb. ammonium oleate, plus 2 ozs. zinc sulphate (Lead arsenate Dynamite)	Winesap	6
	11	4 lbs. calcium arsenate, 2 qts. medium mineral oil (92 U. R. 65-70 visc.) 0.17 lb. ammonium oleate, plus 3 ozs. zinc sulphate (Ca. arsenate Dynamite)	Winesap	6
	12	3 lbs. lead arsenate, 1 pt. herring oil, kerosene 3 pts., 0.17 lb. ammonium oleate, and 2 ozs. zinc sulphate (Lead arsenate, modified Dynamite)	Winesap	6
1938	13	3 lbs. lead arsenate, 1 pt. herring oil with 5 per cent oleic acid	Delicious	1
		3 lbs. lead arsenate, 1 pt. herring oil, 3 pts. kerosene, 0.17 lb. ammonium oleate, and 2 ozs. zinc sulphate (Lead arsenate, modified Dynamite)		5
	14	3 lbs. lead arsenate, 1 pt. herring oil with 5 per cent oleic acid	Delicious	1
		3 lbs. lead arsenate, 2 qts. medium mineral oil (90 U. R. 65-70 visc.) 0.17 lb. ammonium oleate, 2 ozs. zinc sulphate (Lead arsenate Dynamite)		2
		3 lbs. cryolite, 1 pt. herring oil with 5 per cent oleic acid		3
	15	3 lbs. lead arsenate, 1 pt. herring oil with 5 per cent oleic acid	Delicious	1
		Two-thirds pt. nicotine sulphate; 2 qts. light mineral oil (90 U. R. visc. 50-55) casein ammonia		2
		3 lbs. cryolite; 1 pt. herring oil with 5 per cent oleic acid		3
	16	3 lbs. lead arsenate; 1 pt. herring oil with 5 per cent oleic acid	Delicious	1
		3 lbs. calcium arsenate; 2 qts. medium mineral oil (90 U. R. visc. 70-75); casein ammonia; 4 ozs. zinc sulphate		2
		3 lbs. cryolite; 1 pt. herring oil with 5 per cent oleic acid		3

Year	Spray program No.	Materials used per 100 gallons	Apple variety	Number of sprays
1939	17	3 lbs. lead arsenate; 1 pt. herring oil; 3 qts. stove oil 34+; 0.17 lb. ammonium oleate (Lead arsenate modified Dynamite)	Delicious	1
		5 lbs. bentonite, 1 pt. nicotine sulphate, 1 pt. herring oil		5
		½ pt. nicotine sulphate; 2 qts. medium mineral oil (90 U. R. 70-75 visc.)		3
	18	3 lbs. lead arsenate; 1 pt. herring oil; 3 pts. stove oil 34+; 0.17 lb. ammonium oleate (Lead arsenate modified Dynamite)	Delicious	1
		3 lbs. cryolite; 1 pt. herring oil; 3 pts. stove oil 34+; 0.17 lb. ammonium oleate; 4 ozs. zinc sulphate (Fluorine modified Dynamite)		5
		3 lbs. cryolite; 1 pt. herring oil		2
	19	3 lbs. lead arsenate; 1 pt. herring oil; 3 pts. stove oil 34+; 0.17 lb. ammonium oleate (Lead arsenate modified Dynamite)	Delicious	1
		3 lbs. lead arsenate; 0.17 lb. ammonium oleate; 2 qts. medium mineral oil, (70 U.R. visc. 70-75); 4 ozs. zinc sulphate (Lead arsenate Dynamite)		5
		3 lbs. cryolite; 1 pt. herring oil		2
1940	20	3 lbs. lead arsenate; 1 pt. herring oil	Delicious	1
		3 lbs. lead arsenate; 1 qt. light-medium mineral oil, (80 U. R. 60-65 visc.) 1 qt. stove oil 34+; and Multifilm		1
		2 lbs. lead arsenate; 2 qts. medium mineral oil (92 U. R. 70-75 visc.)		2
		3 lbs. cryolite; 1 pt. herring oil		4
	21	3 lbs. lead arsenate; 1 pt. herring oil	Delicious	1
		3 lbs. lead arsenate; two-thirds gal. light mineral oil (80 U. R. 50 visc.)		7
	22	3 lbs. lead arsenate; 1 pt. herring oil	Delicious	1
		2 lbs. Xanthone spray material; ¼ lb. ammonium oleate; 6 ozs. zinc sulphate		8
1941	23	3 lbs. lead arsenate; 1/6 lb. Fluxit	Delicious	1
		3 lbs. lead arsenate; 2 qts. light medium mineral oil (92 U. R. 60 visc.)		8
	24	3 lbs. lead arsenate; 1/6th lb. Fluxit	Delicious	1
		3 lbs. cryolite; 2 qts. light-medium mineral oil (92 U. R. 60 visc.)		8

Table II. The Determinations Made of Photosynthetic Activity of Apple Leaves from 1935 to 1941 Inclusive

Year	Spray program (See Table I)	No. of daily determinations	No. of replications for each determination	Total No. of leaves per plot during season	No. of leaves per envelope	Apple variety
1935	1	46	3	25	1	Jonathan
	2	46	3	22	1	Jonathan
	3	46	3	21	1	Jonathan
	4	46	3	22	1	Jonathan
1936	5	11	3	9	1	Jonathan
	6	11	3	9	1	Jonathan
	7	28	3-4	26	1	Jonathan
	8	28	3-4	29	1	Jonathan
	9	17	4	20	1	Jonathan
1937	10	30	3	3	1	Winesap
	11	30	2-3	3	1	Winesap
	12	30	2-3	3	1	Winesap
1938	13	20	2-3	27	9	Delicious
	14	20	3	27	9	Delicious
	15	20	3	27	9	Delicious
	16	20	3	27	9	Delicious

Year	Spray program (See Table I)	No. of daily determinations	No. of replications for each determination	Total No. of leaves per plot during season	No. of leaves per envelope	Apple variety
1939	17	5	3	27	9	Delicious
	18	5	3	27	9	Delicious
	19	5	3	27	9	Delicious
1940	20	14	3	81	9	Delicious
	21	14	3	81	9	Delicious
	22	14	3	81	9	Delicious
1941	23	9	3	54	9-10	Delicious
	24	9	3	54	9-10	Delicious

Table III. The Average Carbon Dioxide Intake of Jonathan Apple Leaves as Affected by Spray Program (Mgs. $CO_2/dm^2/hr$)†

1935

Det. No.*	Date	(1)‡ Pb.–M.O.	(2)‡ Pb.–H.O.	(3)‡ Ca.–M.O.	(4)‡ Ca.–Zn.	Time of spray
1	7/20	4.30	4.04	8.17	5.18	
2	7/22	6.98	6.92	6.54	7.32	
3	7/23	5.36	8.42	6.70	9.11	
4	7/25	5.50	8.28	7.39	8.50	
5	7/26	5.61	9.78	8.63	9.26	5th cover spray
6	7/29	6.49	8.43	8.16	7.66	
7	7/30	3.42	5.48	5.53	6.90	
8	7/31	6.28	9.48	8.99	8.96	
9	8/2	4.55	5.33	5.47	5.91	
10	8/3	6.15	9.72	8.92	8.13	
11	8/5	4.27	7.59	5.76	6.92	
12	8/6	6.93	8.09	6.28	6.43	
13	8/7	7.33	7.66	6.99	6.35	6th cover spray
14	8/8	5.55	8.06	6.19	6.97	
15	8/9	7.77	9.87	7.67	8.64	
16	8/10	4.68	5.84	5.78	6.14	
17	8/13	5.08	6.13	4.43	5.60	
18	8/14	4.43	7.61	4.43	6.21	
19	8/15	5.65	7.31	4.99	6.34	7th cover spray
20	8/19	7.49	3.86	6.28	4.85	
21	8/20	6.23	4.54	5.83	6.03	
22	8/21	3.90	4.30	4.40	6.59	
23	8/22	6.21	4.74	4.98	6.27	
24	8/26	7.59	14.19	19.66	9.75	
25	8/27	9.13	11.04	15.78	11.67	
26	8/28	7.77	10.73	18.95	11.63	
27	8/29	7.06	8.92	12.87	9.92	
28	8/30	6.57	11.81	18.15	9.07	
29	9/2	7.57	12.97	15.99	9.33	
30	9/3	--	13.98	13.07	14.12	
31	9/5	7.57	12.14	10.77	8.42	
32	9/6	8.37	12.63	10.31	13.59	
33	9/7	8.60	12.74	12.44	11.56	
34	9/9	6.15	12.70	12.75	10.87	
35	9/10	5.71	9.54	7.29	8.15	
36	9/13	7.00	10.21	11.83	8.87	
37	9/16	6.69	10.22	11.29	8.13	
38	9/17	7.44	12.03	12.86	11.90	
39	9/18	6.80	10.96	10.70	9.30	
40	9/19	5.68	9.68	9.73	7.88	
41	9/20	5.13	11.16	12.37	10.60	
42	9/21	7.63	9.50	11.56	11.46	
43	9/24	8.19	9.48	10.57	10.95	
44	9/25	6.46	7.46	9.78	8.93	
45	10/5	8.34	8.40	13.15	9.79	
46	10/8	5.94	5.80	7.90	8.41	
	Av.	6.39	8.90	9.53	8.58	

* Runs Nos. 1 to 23 inclusive were made with leaves in the shade; and 24 to 46 inclusive were made with leaves in the sun.

† Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour.

‡ Numbers in parentheses refer to spray program as given in Table I.

Table IV. The Average Carbon Dioxide Intake of Jonathan Apple Leaves as Affected by Spray Program (Mgs. $CO_2/dm^2/hr.$)*

1936

Det. No.	Date	(5)† Pb.–H.O.	(6)† Nic.–sulf.–oil	(7)† Pb.–Dyn.	(8)† Cal.–Zn.	(9)† Cal.–oil
1	6/29	13.37	6.64	16.06	16.86	(5th cover
2	7/1	15.96	6.75	16.65	19.03	spray June
3	7/2	8.18	4.97	9.10	8.82	19)
4	7/7	13.70	7.33	15.21	19.96	
5	7/9	13.38	10.69	16.83	16.76	
6	7/10	11.78	10.11	13.50	15.71	
7	7/13	15.01	11.90	13.43	16.36	
8	7/14	12.42	13.18	15.62	17.68	
9	7/16	14.86	11.01	10.69	16.71	(6th cover
10	7/20	16.29	11.04	10.59	18.21	spray July
11	7/21	14.87	10.15	9.91	17.26	23)
Av.		13.62	9.43	13.42	16.67	
‡						
12	7/27			15.30	15.84	17.64
13	7/28			14.44	16.62	17.61
14	7/30			10.56	15.07	15.21
15	7/31			11.64	14.85	17.51
16	8/4			10.77	17.81	15.92
17	8/6			10.19	17.00	15.86
18	8/7			12.99	16.27	14.46
19	8/10			11.38	18.31	15.83
20	8/13			12.58	14.82	13.32
21	8/17			12.04	14.77	10.82
22	8/18			12.63	17.46	13.74
23	8/19			12.46	15.69	11.92
24	8/21			8.97	14.67	10.78
25	8/25			7.66	9.35	9.57
26	8/26			8.92	15.21	12.85
27	8/27			10.85	15.35	11.71
28	8/28			9.94	14.57	12.53
Av.				11.37	15.51	13.96

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour.

† Numbers in parentheses refer to the spray program as given in Table I.

‡ A change in trees and plots was made on August 27 and plots 5 and 6 were dropped, and Plot 9 was added.

Table V. The Average Carbon Dioxide Intake of Winesap Apple Leaves as Affected by the Spray Program (Mgs, $CO_2/dm^2/hr.$)*

1937

Det. No.	Date	Un-sprayed	(10)† Pb. Dyn.	Un-sprayed	(11)† Ca. Dyn.	Un-sprayed	(12)† Pb. Mod. Dyn.	Time of spray
1	7/2	10.76	8.58	10.72	10.00	11.70	9.24	5th cover spray
2	7/7	15.76	5.07	14.57	11.32	14.90	7.42	
3	7/8	18.67	8.69	14.27	6.50	14.39	--	
4	7/9	19.44	8.15	14.77	12.06	16.08	11.63	
5	7/13	--	7.66	12.59	8.17	10.10	11.98	
6	7/15	14.21	9.16	11.99	8.71	13.86	--	
7	7/16	12.73	9.60	14.45	8.81	15.48	8.64	
8	7/19	14.02	7.87	11.91	10.74	10.67	11.42	
9	7/20	14.03	6.50	11.52	8.29	12.56	--	
10	7/21	11.52	4.97	14.26	9.98	9.09	8.74	
11	7/23	14.94	10.13	15.98	10.66	13.13	13.02	
12	7/27	14.19	9.22	16.32	6.65	15.65	11.02	
13	7/30	11.89	11.10	13.06	11.56	11.29	10.08	
14	8/2	11.70	8.07	15.86	10.61	12.09	13.37	
15	8/3	13.96	7.67	11.16	10.17	10.15	10.54	
16	8/5	12.23	8.72	12.36	7.53	10.45	11.11	
17	8/6	12.42	7.93	14.98	8.17	9.83	8.25	6th cover spray
18	8/9	13.66	8.62	15.11	9.94	11.95	11.25	
19	8/10	16.65	9.58	11.80	9.39	9.40	12.59	
20	8/12	8.60	8.81	9.58	6.71	8.64	8.01	
21	8/13	9.22	7.98	12.26	6.93	11.04	10.42	
22	8/16	10.89	6.59	12.00	9.13	8.01	7.58	
23	8/17	10.35	6.87	11.00	8.12	10.13	10.17	
24	8/19	13.00	6.36	11.62	6.80	9.32	10.00	
25	8/20	12.96	7.80	11.27	8.00	8.25	8.61	
26	8/24	13.78	6.98	12.34	9.45	9.97	8.33	
27	8/25	--	6.24	9.91	6.97	9.21	8.51	
28	8/27	8.73	6.94	11.47	7.02	7.34	7.42	
29	8/31	8.02	5.25	10.14	5.59	8.91	5.90	
30	9/1	12.20	6.47	13.79	7.85	7.69	6.57	
Av.		12.88	7.78	12.77	8.73	11.04	9.70	

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour

† Numbers in parentheses refer to the spray program as given in Table I.

Table VI. The Average Carbon Dioxide Intake of Delicious Apple Leaves as Affected by Spray Program (Mgs, $CO_2/dm^2/hr$)*

1938

Det. No.	Date	Unsprayed	(13)† Mod. L.A. Dyn.	(14)† L.A. Dyn. F.	(15)† Nic. oil F.	(16)† Cal. ars. oil F.	Time of spray
1	6/24	9.28	9.19	3.32	10.49	11.03	3rd cover spray
2	6/28	12.47	9.31	10.02	15.16	12.85	
3	6/30	11.40	11.45	10.42	14.16	13.99	
4	7/6	11.47	14.12	11.10	12.80	13.09	
5	7/7	9.92	11.28	10.69	8.56	10.53	
6	7/12	9.53	11.13	10.61	12.45	11.31	
7	7/14	10.74	8.19	7.35	7.15	7.12	4th cover spray
8	7/19	10.68	12.15	12.27	12.94	10.86	
9	7/21	10.11	9.97	9.61	8.36	7.61	5th cover spray
10	7/26	8.19	9.74	10.48	9.59	7.83	
11	7/28	8.43	10.62	11.60	10.60	9.06	
12	8/4	7.97	9.95	9.86	10.24	8.85	
13	8/6	8.43	8.30	11.39	9.30	8.14	6th cover spray
14	8/9	9.86	10.75	10.74	7.47	8.83	
15	8/11	8.85	10.23	10.13	6.17	7.29	
16	8/16	7.44	8.88	10.07	7.83	6.67	
17	8/18	8.40	9.09	11.99	8.98	8.35	
18	8/23	9.14	9.18	11.63	8.64	7.40	
19	8/25	9.48	9.52	8.21	7.85	8.66	
20	8/31	9.12	7.25	9.63	9.19	8.19	
	Av.	9.55	10.01	10.06	9.90	9.38	

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour.
† Numbers in parentheses refer to the spray program as given in Table I.

Table VII. The Average Carbon Dioxide Intake of Delicious Apple Leaves as Affected by Spray Program. (Mgs. $CO_2/dm^2/hr.$)*

1939

Det. No.	Date	(17)† Nic. Bentonite + nic. oil	Unsprayed	(18)† Mod. L.A.Dyn. Mod. cry. cry. Dyn; cry-H.O.	Unsprayed	(19)† Mod. L. A Dyn; cry-olite+M.O.	Unsprayed	Time of spray
1	9/5	6.92	7.79	12.39	11.14	7.44	9.98.	
2	9/8	7.97	6.47	10.83	7.75	6.37	6.74	
3	9/12	10.31	9.17	11.96	12.71	9.33	10.78	
4	9/15	10.11	8.26	9.15	11.09	8.55	8.86	Last cover
5	9/19	10.15	9.71	10.95	11.75	6.06	10.38	spray Aug. 16
Av.		9.09	8.28	11.06	10.89	7.55	9.34	

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour.

† Numbers in parentheses refer to the spray program as given in Table I.

Table VIII. The Average Carbon Dioxide Intake of Delicious Apple Leaves as Affected by Spray Program, (Mgs. $CO_2/dm^2/hr.$)*

1940

Det. No.	Date	(2)† Lead ars. M.O; Cry. herring oil	Unsprayed	(21)† Lead ars. M.O.	Unsprayed	(22)† Xanthone	Unpsrayed	Time of spray
1	6/18	10.06	13.40	15.07	10.34	13.51	14.68	4th cover spray
2	6/24	10.24	9.51	12.68	12.01	11.21	12.30	June 15
3	6/27	13.70	13.51	17.85	15.38	16.82	17.00	
4	7/2	13.33	12.94	14.59	13.10	11.19	14.08	
5	7/5	13.00	14.99	13.31	13.53	9.91	12.17	5th cover spray
6	7/9	8.10	8.40	7.99	6.91	5.80	11.28	
7	7/17	15.21	11.96	13.21	14.13	13.41	15.84	
8	7/18	12.17	10.20	11.12	12.84	8.52	12.31	6th cover spray
9	7/24	8.64	13.28	11.27	12.65	11.57	13.55	
10	7/30	12.14	14.37	11.94	12.40	11.54	15.18	7th cov. sp. 7/29
11	8/20	14.81	12.36	9.13	10.07	18.23	14.12	8th cov. sp. 8/16
12	8/23	11.32	13.16	10.54	10.40	14.47	14.75	
13	9/5	14.73	16.05	15.61	13.81	17.63	17.42	
14	9/11	9.02	10.52	9.45	10.01	13.45	12.03	
Av.		11.89	12.48	12.41	11.97	12.66	14.05	

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour.

† Numbers in parentheses refer to the spray program as given in Table I.

Table IX. The Average Carbon Dioxide Intake of Delicious Apple Leaves as Affected by Spray Program, (Mgs. $CO_2/dm^2/hr$)*

1941

Det. No.	Date	(23)† Lead Ars.-mineral oil	(24)† Cryolite + min. oil	Unsprayed	Time of spray
1	6/14	12.1	12.9	14.4	
2	6/17	7.0	5.5	9.8	
3	6/19	10.8	9.6	12.0	5th cover spray
4	6/25	10.5	9.6	13.0	
5	7/1	12.1	10.7	11.4	
6	7/3	11.3	10.0	13.3	6th cover spray
7	7/9	11.2	11.4	12.3	
8	7/18	12.1	10.3	10.3	
9	7/22	10.6	10.6	11.0	7th cover spray
	Av.	10.9	10.1	11.9	

* Milligrams of carbon dioxide absorbed per square decimeter of leaf surface per hour

† Numbers in parentheses refer to the spray program as given in Table I.

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